U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
GRAND CANYON MONITORING AND RESEARCH CENTER

Daily and Seasonal Variability of pH, Dissolved Oxygen, Temperature, and Specific Conductance in the Colorado River Between the Forebay of Glen Canyon Dam and Lees Ferry, Northeastern Arizona, 1998–99

Open-File Report 01–222

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2001**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Daily and Seasonal Variability of PH, Dissolved Oxygen, Temperature, and Specific Conductance in the Colorado River Between the Forebay of Glen Canyon Dam and Lees Ferry, Northeastern Arizona, 1998-99**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Department of the Interior 1849 C Street, NW Washington, DC 20240**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**18**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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Daily and Seasonal Variability of pH, Dissolved Oxygen, Temperature, and Specific Conductance in the Colorado River Between the Forebay of Glen Canyon Dam and Lees Ferry, Northeastern Arizona, 1989–99

By M.E. Flynn, R.J. Hart, G.R. Marzolf, and C.J. Bowser

Water-Resources Investigations Report 01—4240

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GRAND CANYON MONITORING AND RESEARCH CENTER

Tucson, Arizona
2001

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Cover photograph: Mile -9 in Glen Canyon. (Photograph by Carl J. Bowser, University of Wisconsin, Department of Geology and Geophysics.)

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CONVERSION FACTORS

Multiply	By	To obtain
meter (m)	3.281	foot
kilometer (km)	0.6214	mile

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°F = (1.8\ °C) + 32$$

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing solute mass (milligrams) per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C). pH is given in standard pH units.

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)— a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called “Sea Level Datum of 1929”.

Daily and Seasonal Variability of pH, Dissolved Oxygen, Temperature, and Specific Conductance in the Colorado River Between the Forebay of Glen Canyon Dam and Lees Ferry, Northeastern Arizona, 1998–99

By M.E. Flynn, R.J. Hart, G.R. Marzolf, *and* C.J. Bowser[1]

Abstract

The productivity of the trout fishery in the tailwater reach of the Colorado River downstream from Glen Canyon Dam depends on the productivity of lower trophic levels. Photosynthesis and respiration are basic biological processes that control productivity and alter pH and oxygen concentration. During 1998–99, data were collected to aid in the documentation of short- and long-term trends in these basic ecosystem processes in the Glen Canyon reach. Dissolved-oxygen, temperature, and specific-conductance profile data were collected monthly in the forebay of Glen Canyon Dam to document the status of water chemistry in the reservoir. In addition, pH, dissolved-oxygen, temperature, and specific-conductance data were collected at five sites in the Colorado River tailwater of Glen Canyon Dam to document the daily, seasonal, and longitudinal range of variation in water chemistry that could occur annually within the Glen Canyon reach.

INTRODUCTION

The reach of the Colorado River downstream from Glen Canyon Dam (tailwater) is widely known for its trout fishery. The productivity of the fishery depends on the productivity of lower trophic levels, in this case, the photosynthetic reduction of carbon by the benthic flora and their epiphytes and the invertebrate grazers supported by these plants (Blinn and Cole, 1991). An objective of monitoring plant productivity is to provide documentation of long-term trends in basic ecosystem processes such as photosynthesis. The most direct way to do this is to measure changes in biomass through time at known locations in the area of interest. In the Colorado River, this direct approach is compromised by the spatial variability and the diversity of the benthic flora so that a sampling program that is frequent and valid is prohibitively expensive. An alternative approach that has shown promise (Marzolf and others, 1999) is to measure chemical properties of the river—oxygen concentration and pH—that are mediated by the growth of plants. During 1998–99, the U.S. Geological Survey (USGS), in cooperation with the Grand Canyon Monitoring and Research Center (GCMRC), made depth-profile measurements of dissolved oxygen, temperature, and specific conductance in the forebay of Glen Canyon Dam. In addition, pH, dissolved oxygen,

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temperature, and specific conductance were measured at five locations along the Colorado River below Glen Canyon Dam downstream to Lees Ferry.

The basic relations governing oxygen (O_2) production and carbon dioxide (CO_2) removal (increasing pH) by photosynthesis and O_2 removal and CO_2 production (decreasing pH) by respiration are given by:

$$CO_2 + H_2O \rightarrow \text{organic carbon} + O_2 \quad \text{(photosynthesis)},$$

and

$$O_2 + \text{organic carbon} \rightarrow CO_2 + H_20 \quad \text{(respiration)}.$$

The relation between CO_2 change and pH depends on the buffering capacity of the water (H_2O) and can be developed from:

$$A_c = K_h K_{a1} P_{CO_2}\left[\frac{1}{a_{H^+}} + \frac{2K_{a2}}{a_{H^+}}\right],$$

where

A_c	=	carbonate alkalinity,
P_{CO_2}	=	partial pressure of CO_2 in equilibrium with the solution,
K_h	=	Henry's law constant for CO_2,
a_H^+	=	hydrogen ion concentration, and
K_{a1} and K_{a2}	=	thermodynamic dissociation constants for the carbonate system (Morse and MacKenzie, 1990).

By converting the pH data with this relation, carbon uptake can be estimated.

This approach has the appeal of integrating the spatial variability between selected points in the reach and yields an estimate of the cumulative metabolism (photosynthesis and respiration) of the reach. Furthermore, the measurements can be made by deploying O_2 and pH sensors in automated dataloggers that can be programmed to record data at frequent intervals. Daily estimates of photosynthetic-carbon assimilation by the benthic flora in the reach can be computed using this approach.

Purpose and Scope

The purpose of this report is to present data collected for the GCMRC by the USGS in the forebay and tailwater of Glen Canyon Dam in 1998–99. Dissolved-oxygen, temperature, and specific-conductance profile data were collected to document the monthly status of water chemistry in the forebay of Glen Canyon Dam. To document the daily, seasonal, and longitudinal range of variation in water quality that could occur annually within the Glen Canyon reach, pH, dissolved-oxygen, temperature, and specific-conductance data were collected from the river below Glen Canyon Dam.

Physical Setting

In the study reach, the Colorado River flows through Glen Canyon from Glen Canyon Dam to Lees Ferry, Arizona, a distance of about 25 km (**fig. 1**). The elevation of the Colorado River changes from about 955 m at the base of the dam to 947 m at Lees Ferry. Water is released from Lake Powell to the Colorado River below Glen Canyon Dam through eight penstocks. The penstock intakes are at an elevation of about 1,058 m and withdraw water from a depth of about 70 m when the lake is near maximum capacity. The minimum lake-level elevation needed to produce power is about 1,064 m. Below the dam, the reach of the river is broad and flat with no rapids. The channel cross section varies from broad cobbled riffles to deep pools that contain fine sands. Shallower bars nearest the dam are thought to be armored with cobble because of the absence of a sediment source (Pemberton, 1976). The walls of Glen Canyon are nearly vertical, and the rim is about 200 m above the river. The duration of light at the river surface throughout the year is affected by the north-south and east-west orientation of the canyon.

The confluence of the Paria River with the Colorado River just downstream from Lees Ferry marks the end of the reach of interest because this tributary periodically contributes sediment loads that effectively limit the light continuously available for photosynthesis. Upstream from the confluence of the Paria River, the Colorado River generally is free of sediment.

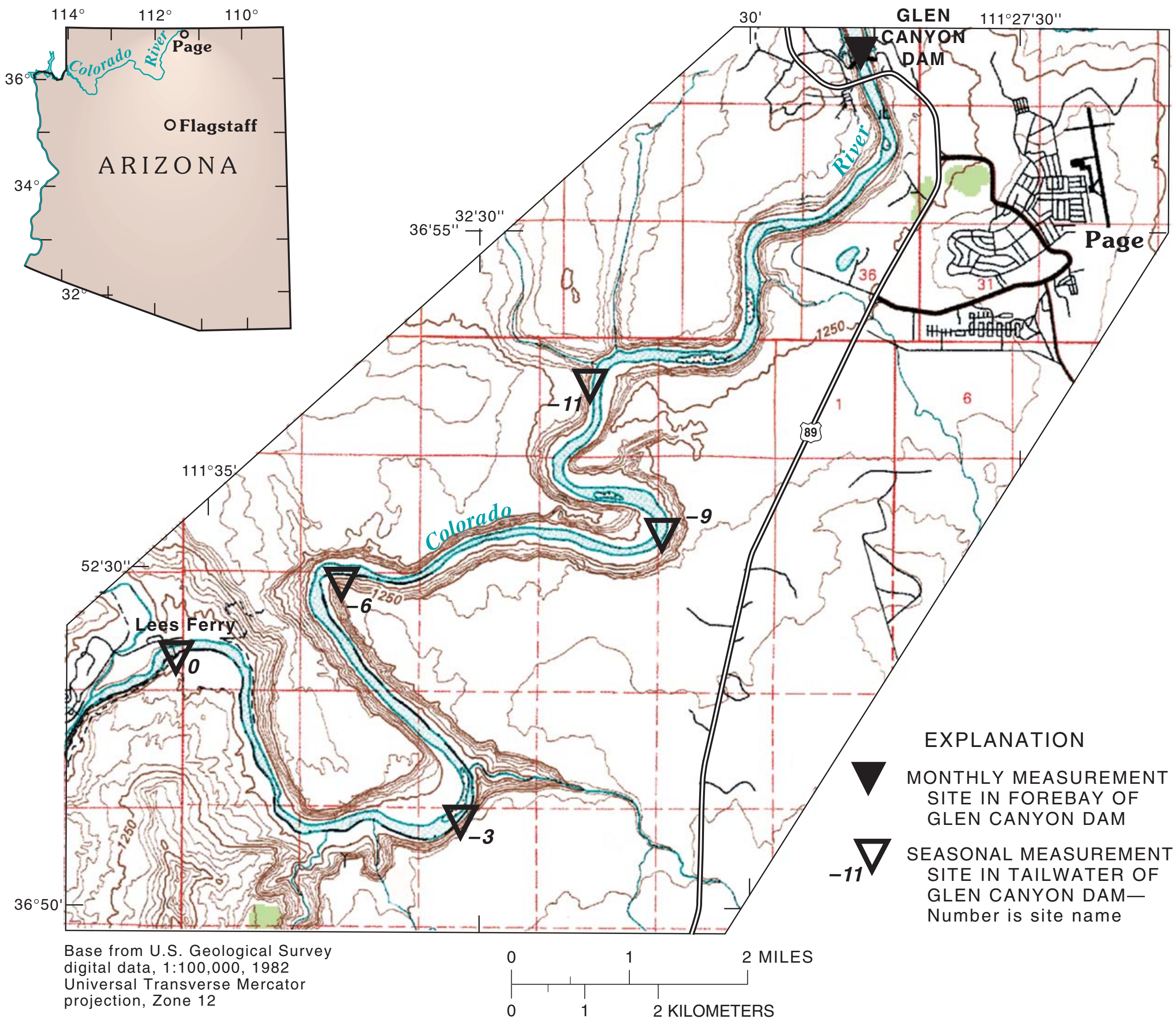

Figure 1. Location of study area and measurement sites in the forebay and tailwater of Glen Canyon Dam.

Previous Investigations

Angradi and Kubly (1993) described the effects of atmospheric exposure on chlorophyll *a*, biomass, and productivity of the epilithon (a biological film that converts organic matter into food for larger organisms) of a tailwater. Hart and Sherman (1996) documented that the physical and chemical characteristics of outflows through the draft tubes of Glen Canyon Dam were similar to the physical and chemical characteristics of the water in Lake Powell at penstock depth and deeper depths. Marzolf and others (1999) documented that the daily oscillations in pH and oxygen concentration in this reach of the river were caused by photosynthesis and respiration of the Glen Canyon benthic community and that the 1996 controlled flood reduced the plant biomass by scouring. The changes in the benthic flora that occurred as a result of the controlled flood in 1996 were documented by McKinney and others (1999). Brock and others (1999) demonstrated that the effects of the 1996 controlled flood increased the net photosynthetic rates of *Cladophora glomerata* (a species of algae).

METHODS AND STUDY DESIGN

Multiprobe dataloggers were used to measure pH, dissolved oxygen, temperature, and specific conductance in the forebay and tailwater of Glen Canyon Dam during 1998–99. Data collected from the pH probe on the multiprobe datalogger used in the forebay are not reported because the probe was mounted horizontally on the logger and resulted in fluctuating measurements. Measurements were scheduled to document daily and seasonal variability.

Historically, locations between Glen Canyon Dam and Lees Ferry have been referenced in terms of negative river miles upstream from Lees Ferry, which is at river mile 0. For consistency, the measuring sites in the tailwater of Glen Canyon Dam established during this study are referenced using this protocol. For example, the site 3 mi upstream from Lees Ferry is referred to as the -3-mile site.

Measurements in the Forebay of Glen Canyon Dam

Monthly profile measurements of dissolved oxygen, temperature, and specific conductance were made in the center of the forebay of Glen Canyon Dam from March 1998 to August 1999 (table 1). Measurements generally were made during the third week of the month; measurements in June, September, and December 1998, and March and June 1999 corresponded with data-collection trips in the tailwater area.Profile measurements were made with a Sea-Bird Electronics Seacat SBE 19-03 multiprobe datalogger. The logger was equipped with internal memory and batteries, a pressure transducer, and a submersible pump to control the passage of water sampled by the dissolved-oxygen, temperature, and specific-conductance sensors. The offset coefficient of the pressure transducer was calculated before each profile to adjust to changes in atmospheric pressure. The oxygen probe was calibrated at 0-percent and 100-percent saturation before each data-collection trip. The temperature and specific-conductance sensors were calibrated annually by the manufacturer and found to be stable and accurate. The oxygen probe failed during the data-collection trip in December 1998.

The datalogger on the profiler was programmed to scan the sensors at 0.5-second intervals. Down casts were controlled to a descent rate of less than free fall (0.5-1.0 m/s). At this sampling interval and descent rate, the profiler recorded measurements from each sensor two or three times per meter. The reservoir elevation was recorded for each trip (table 1).

Table 1. Date, time, and reservoir-elevation data for monthly forebay data-collection trips, March 1998–August 1999

Date	Profile starting time	Reservoir elevation, in meters above sea level	Date	Profile starting time	Reservoir elevation, in meters above sea level
03–20–98	9:25	1,119.67	12–09–98	12:55	1,123.19
05–01–98	9:24	1,120.46	01–25–99	14:21	1,121.00
05–27–98	9:05	1,123.86	02–25–99	10:59	1,121.39
06–11–98	10:06	1,125.65	03–24–99	15:45	1,120.99
07–17–98	10:05	1,126.78	04–28–99	12:12	1,120.86
08–13–98	10:35	1,125.89	05–20–99	12:36	1,121.36
09–30–98	15:19	1,124.06	06–24–99	10:26	1,125.16
10–22–98	11:44	1,123.53	07–15–99	11:30	1,126.13
11–23–98	10:43	1,123.43	08–19–99	12:07	1,125.82

Measurements in the Tailwater of Glen Canyon Dam

The selection of dates in June, September-October, and December 1998, and March and June 1999 was designed to document the differences in daily ranges of pH and oxygen concentration under the extremes of light and water temperature that might be experienced annually within the reach. These times were selected so that the range of seasonal variation in length of day would be represented in the data as the longest days in summer and the shortest days in winter. Owing to thermal stratification, the temperature of the water released from Lake Powell was expected to be lower in spring and higher in fall.

Five sites between Glen Canyon Dam and Lees Ferry were selected for measurement of pH, dissolved oxygen, temperature, and specific conductance (fig. 1). These sites were about 4.8 km apart and defined subreaches with different canyon orientations. The -11-mile site defined the inflow to the subreach from -11 mile to -9 mile. This subreach contains north-south and east-west canyon orientations. The -9-mile site defined the inflow to the subreach from -9 mile to -6 mile, a subreach with an east-west orientation. During the data collection trips in June, September-October, and December 1998, and March 1999, this site was about 3 m upstream from a discharging spring. Because of the noisy data signal caused by the influence of the spring, the site was moved farther upstream for the data-collection trip in June 1999. The -6-mile site defined the inflow to the subreach from -6 mile to -3 mile, which is a subreach with a north-south orientation. The -3-mile site defined the inflow to the subreach from -3 mile to 0 mile. This subreach contains north-south and east-west canyon orientations. The 0-mile site at Lees Ferry was just above the end of the study reach.

Data were collected using Hydrolab MiniSonde multiprobe loggers. All five loggers were equipped with internal memory for data storage during data collection. Four of the loggers also were equipped with internal batteries. One of the loggers required the use of an external battery.

Each logger contained pH, dissolved-oxygen, temperature, and specific-conductance sensors. The sensors for pH, dissolved oxygen, and specific conductance were calibrated before each sampling trip using protocols suggested by the manufacturer. The pH sensors were calibrated using buffer solutions of pH 4.0, 7.0, and 10.0. The dissolved-oxygen sensors were calibrated at 100-percent saturation. The temperature sensors were not calibrated. The specific-conductance sensors were calibrated with known standards that bracketed expected field values.

Immediately before deployment for the sampling trips in June and September-October 1998 and March 1999, and immediately after 2 days of measurement, all loggers were tied together and deployed in the river at the 0-mile site (Lees Ferry). Loggers were steeped in the same water mass for an hour before and an hour after data collection to estimate instrument drift and shifts in calibration over the 48-hour measurement period. Calibration drift of instruments varied from sample period to sample period. Data on probe accuracy and drift characteristics are shown in table 2. The presampling and postsampling difference values are the maximum differences among probes observed during the last half hour of recording.

Table 2. Probe accuracy and drift characteristics

[mg/L, milligrams per liter; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; ±, plus minus; N/A, not applicable]

Date of sampling period	pH, in standard units	Dissolved oxygen (mg/L)	Temperature (°C)	Specific conductance (µS/cm)
		Probe accuracy		
N/A	±0.2	±0.2	±0.10	±0.001
		Presampling maximum probe difference		
June 1998	.09	.50	.08	27
September 1998	.35	.67	.08	14
March 1999	.32	.30	.07	9
		Postsampling maximum probe difference		
June 1998	.41	1.08	.06	24
September 1998	.29	.91	.09	16
March 1999	.33	.82	.09	12

Each logger was programmed to collect data at 5-minute intervals for at least 48 hours. To ensure that the loggers were recording the same water masses passing each station, a staggered start time was used during the trips in June 1998, September-October 1998, and December 1998. The staggered time differences were calculated on the basis of the rated river velocity and discharge data of Graf (1995). Loggers were programmed to stop collecting data at the same time (table 3).

The loggers were deployed using a steel cable and a weight. The steel cable was looped around a tree or a bolt in a rock and then stretched from the bank to the weight that was positioned in the river 2–3 m from the bank. The loggers then were attached to the steel cable so that, as they hung from the cable, they were free from obstructions.

Only the 0-, -3-, -6-, and -9-mile sites were measured during the trips in June 1998. With the exception of the trips in June and December 1998, the same logger was deployed at the same site for each of the collection periods (table 3). During the trip in December, the loggers for the -9-mile site and the -6-mile site were inadvertently switched.

Table 3. Logger deployment information for seasonal tailwater data-collection trips, June, September-October, and December 1998, and March and June 1999

[Dashes indicate no data]

Trip number	Site name (river mile)	Logger serial number	Date of trip		Time of measurement	
			Start	End	Start	End
1	0	34457	06–10–98	06–12–98	4:30	6:00
	-3	34458			3:00	6:00
	-6	34459			1:30	6:00
	-9	34460			0:00	6:00
	-11	([1])			---	---
2	0	33601	09–30–98	10–02–98	7:00	8:00
	-3	34457			5:30	8:00
	-6	34458			4:00	8:00
	-9	34459			2:30	8:00
	-11	34460			1:00	8:00
3	0	33601	12–09–98	12–11–98	7:00	8:00
	-3	34457			5:30	8:00
	-6	34459			4:00	8:00
	-9	34458			2:30	8:00
	-11	34460			1:00	8:00
4	0	33601	03–24–99	03–26–99	1:00	8:00
	-3	34457			1:00	8:00
	-6	34458			1:00	8:00
	-9	34459			1:00	8:00
	-11	34460			1:00	8:00
5	0	33601	06–23–99	06–25–99	1:00	8:00
	-3	34457			1:00	8:00
	-6	34458			1:00	8:00
	-9	34459			1:00	8:00
	-11	34460			1:00	8:00

[1]No probe.

Data Management

Data collected with the Sea-Bird SBE 19-03 were processed using the manufacturer's software (Seasoft version 4.233) and recommended standard processing steps for data from an SBE 19-03 equipped with a submersible pump. The raw hexadecimal data were first converted into derived values of depth, pH, dissolved oxygen, temperature, and specific conductance as ASCII numbers in an engineering format. A low-pass filter then was used to force specific conductance to have the same response with respect to time as temperature. The temperature, dissolved oxygen, and specific-conductance values then were aligned in time relative to pressure to ensure that values of dissolved oxygen were made using measurements from the same parcel of water. Measurements for which the profiler was moving less than the minimum velocity or traveling backwards because of ship roll then were marked as bad. Next, oxygen was computed from oxygen current, oxygen temperature, water temperature, and water pressure. The data then were averaged into 1.0-meter depth bins. Finally, the averaged data were imported into a spreadsheet where depth was converted to elevation above sea level.

Data collected with the Hydrolab MiniSondes were downloaded from the loggers as comma-delimited text files. The files were imported into a spreadsheet for graphing purposes and loaded into the USGS database.

Presentation of Data

Data collected during tailwater data-collection trips are presented graphically in this report, and all data collected during the study are available as comma-delimited ASCII electronic files. Files containing tailwater data are named for the site location in river miles relative to Lees Ferry and the date of the measurement in month-year (mmyyyy) format with a ".tw" extension. For example, the file containing data for the measurement at the -6-mile site during December 1998 is called 06121998.tw. The files contain date, time, temperature, dissolved-oxygen, specific-conductance, and pH data at 5-minute intervals (table 4). Files containing forebay profile-averaged data are named for the date of the measurement in month-day-year (mmddyyyy) format with a ".fb" extension. For example, the file containing the data for the measurement made on August 13, 1998, is called 08131998.fb. The files contain depth, temperature, dissolved-oxygen, and specific-conductance data at 1.0-meter intervals (table 5). Readers who would like to obtain the data in digital form may contact the District Chief, U.S. Geological Survey, WRD, 520 North Park Avenue, Suite 221, Tucson, AZ 85719-5035.

Table 4. Example of seasonal tailwater data file

[Data from -6-mile site. temp, temperature in degrees Celsius; do, dissolved oxygen in milligrams per liter; sc, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH, pH in standard units]

```
date,time,temp,do,sc,pH
            –data not shown–
12/09/1998,23:30,9.92,6.92,640,8.11
12/09/1998,23:35,9.92,6.95,640,8.11
12/09/1998,23:40,9.93,6.91,640,8.11
12/09/1998,23:45,9.93,6.97,640,8.12
12/09/1998,23:50,9.93,6.96,640,8.12
12/09/1998,23:55,9.94,7.00,640,8.12
12/10/1998,0:00,9.94,6.98,640,8.11
12/10/1998,0:05,9.94,6.96,640,8.11
12/10/1998,0:10,9.94,6.96,640,8.12
12/10/1998,0:15,9.94,6.97,639,8.12
12/10/1998,0:20,9.95,6.98,639,8.12
12/10/1998,0:25,9.95,6.97,639,8.12
12/10/1998,0:30,9.96,6.96,639,8.13
            –data not shown–
```

Table 5. Example of monthly forebay profile-data file

[Data from August 13, 1998. depth, in meters; temp, temperature in degrees Celsius; do, dissolved oxygen in milligrams per liter; sc, specific conductance in microsiemens per centimeter at 25 degrees Celsius]

```
depth,temp,do,sc
            –data not shown–
10,23.22,6.55,620
11,21.62,6.99,623
12,20.50,7.32,623
13,19.46,7.32,627
14,18.98,7.01,626
15,18.68,7.32,626
16,18.43,7.41,626
17,18.23,7.20,625
18,18.04,7.17,625
19,17.79,7.27,625
20,17.58,7.27,625
            –data not shown–
```

DISCUSSION OF VARIABILITY OF CONSTITUENTS

The seasonal measurements of pH, dissolved oxygen, temperature, and specific conductance made in the forebay and at the five sites in the tailwater of Glen Canyon Dam are presented graphically. Data collected from the pH probe on the datalogger used in the forebay are not reported because the horizontal mounting of the probe resulted in fluctuating measurements.

Seasonal measurements of pH made at the five sites in the tailwater below Glen Canyon Dam are shown in **figure 2**. The decrease in average pH through time reflects seasonal changes in the pH of Lake Powell at the depth of the penstocks. Small variations among Hydrolab sensors deployed at the same site were not resolved during this study.

Profile measurements of dissolved-oxygen concentrations made in the forebay of Glen Canyon Dam on the dates of the tailwater measurements are shown in **figure 3**. Thermal stratification in June 1998, September 1998, and March 1999 is sufficient to isolate water at hypolimnetic depths from the atmosphere and from lighted zones where photosynthesis releases oxygen. Oxygen concentration decreased at penstock depth from June to September 1998 and increased at penstock depth from March to June 1999.

Measurements of dissolved-oxygen concentration were made at the five sites in the Colorado River tailwater below Glen Canyon Dam and are shown in **figure 4**. The variation in concentration on different dates reflects seasonal changes in the oxygen concentration in the water of Lake Powell at the depth of the penstocks. Small variations among Hydrolab sensors deployed at the same site were not resolved; however, the seasonal variations in oxygen concentrations are much larger, so there is greater likelihood that they are due to seasonal variation in Lake Powell and not just to sensor differences.

In the interpretation of these data, it will be crucial to reconcile the variability among instruments (calibration accuracy and instrument drift) with the comparative measurements of pH and oxygen concentration (daily oscillation in the measurements). Variability occurred among the data from the instruments when the instruments were suspended together in the river before and after deployment (**table 2**). The magnitude of the variation among instruments often exceeds the measured variation within one instrument through the duration of the measurement period. Several classes of interpretation are under consideration to resolve this problem.

(1.) The data are real, and there are no instrument errors.

(2.) The differences among the starting points of the four curves in figures 2 and 4 are due to instrument error, and instrument drift may have occurred. The time-series pattern within each curve, however, is real. Perhaps the minima are similar, perhaps the maxima are similar, or perhaps the means are similar.

(3.) The instrument error among instruments is so large and pervasive that no reconciliation is logically possible.

Nevertheless, there are five features of the data that are notable at this time.

(1.) The pattern of change within instruments is similar for all instruments through any of the measurement periods.

(2.) The increases in pH and dissolved-oxygen concentration occur during the day.

(3.) The decreases in pH and dissolved-oxygen concentration occur at night.

(4.) The amplitudes of daily change portrayed by the five curves increase with increasing distance downstream.

(5.) The times at which peaks occur are delayed by increasing distance downstream.

Measurements of temperature profiles made in the forebay of Glen Canyon Dam on the dates of the tailwater measurements are shown in **figure 5**. Thermal stratification is strong in June and December 1998. By March 1999, the epilimnetic layer had cooled, and the thermal discontinuity had eroded deeply enough so that the temperature of water passing through the penstocks reached its minimum for the period of the study. Temperature measurements made at the five sites in the Colorado River tailwater below Glen Canyon Dam are shown in **figure 6**. The average thermal difference among dates reflected seasonal changes at the depth of the penstocks (fig. 5). Daily warming was observed on all dates. The maximum warming during the day (about 1.3°C) occurred in June, near the summer solstice.

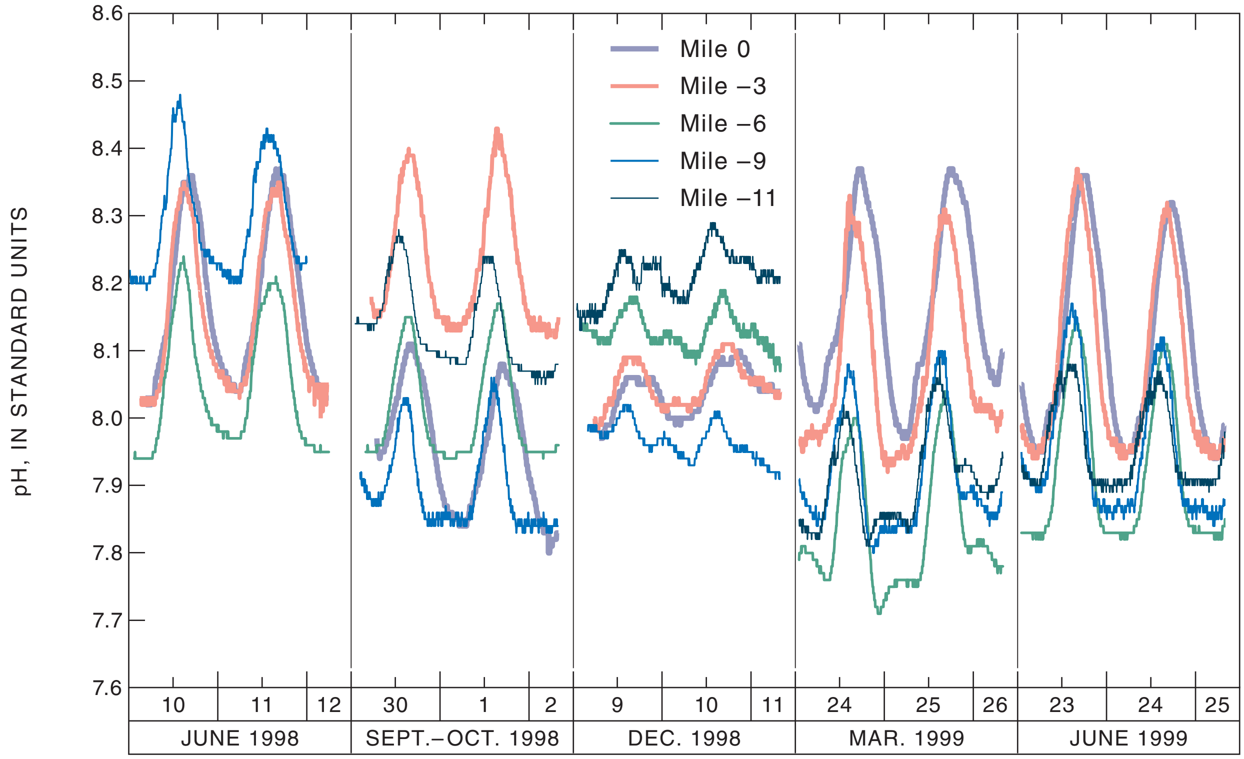

Figure 2. Seasonal pH data collected from the tailwater of Glen Canyon Dam during June, September–October, and December 1998, and March and June 1999.

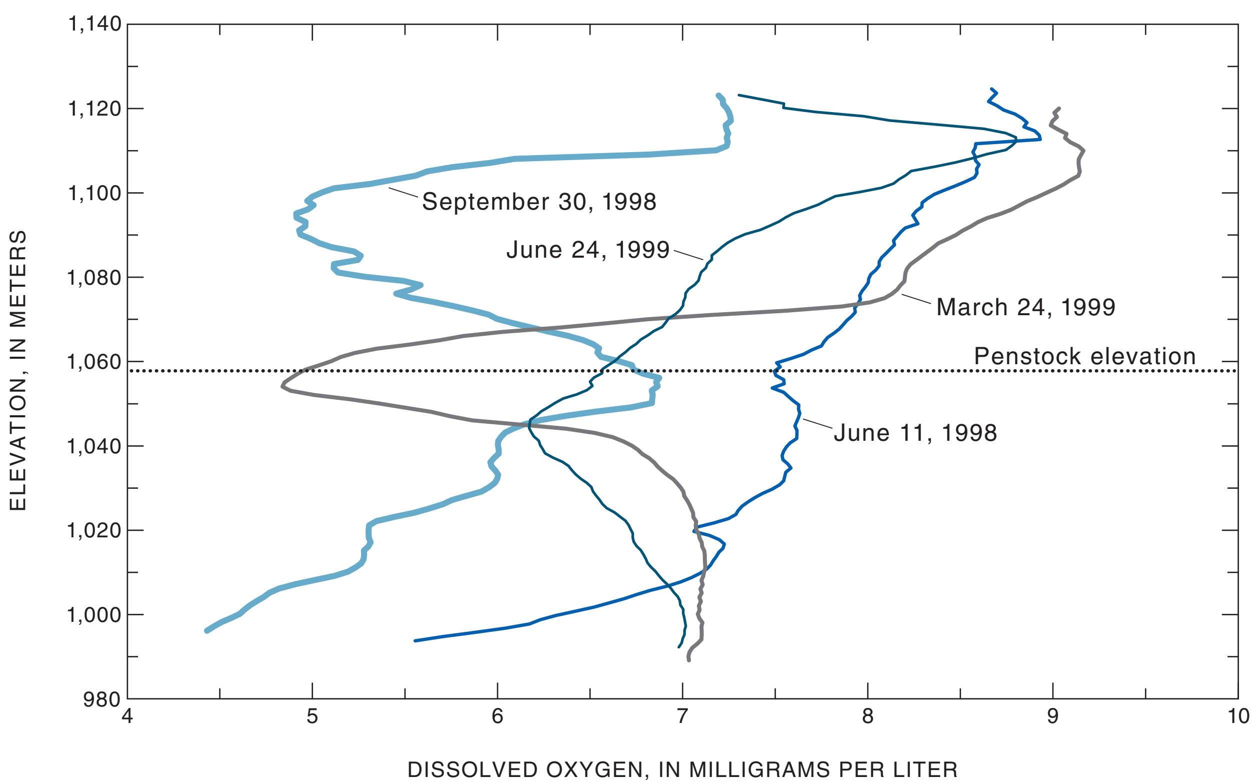

Figure 3. Selected dissolved-oxygen profile data collected from the forebay of Glen Canyon Dam.

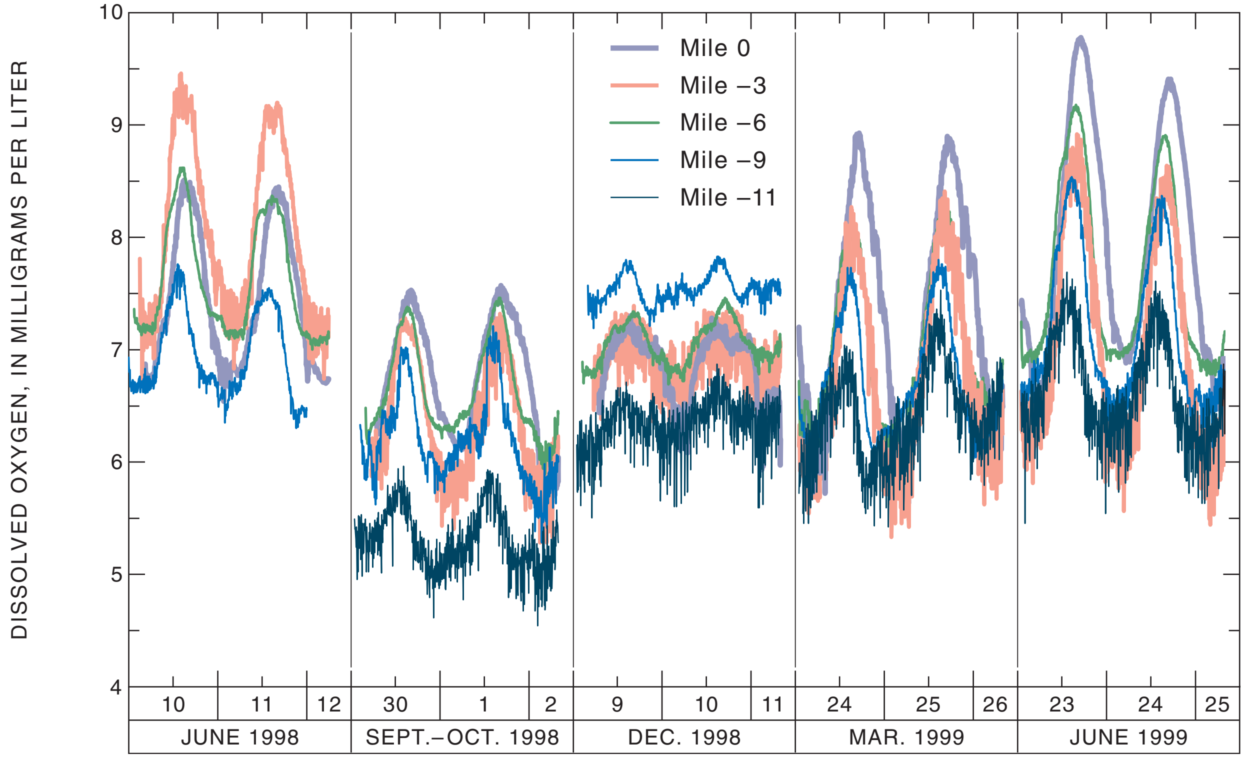

Figure 4. Seasonal dissolved-oxygen data collected from the tailwater of Glen Canyon Dam during June, September-October, and December 1998, and March and June 1999.

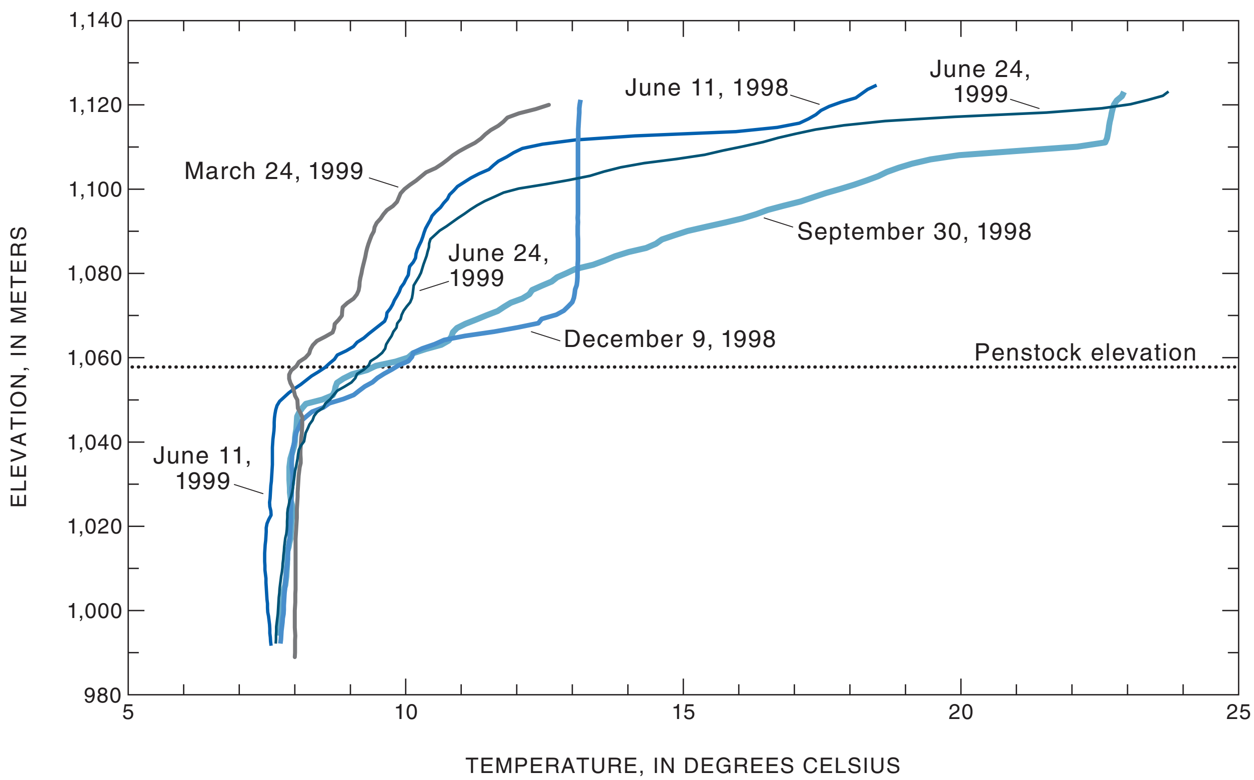

Figure 5. Selected temperature profile data collected from the forebay of Glen Canyon Dam.

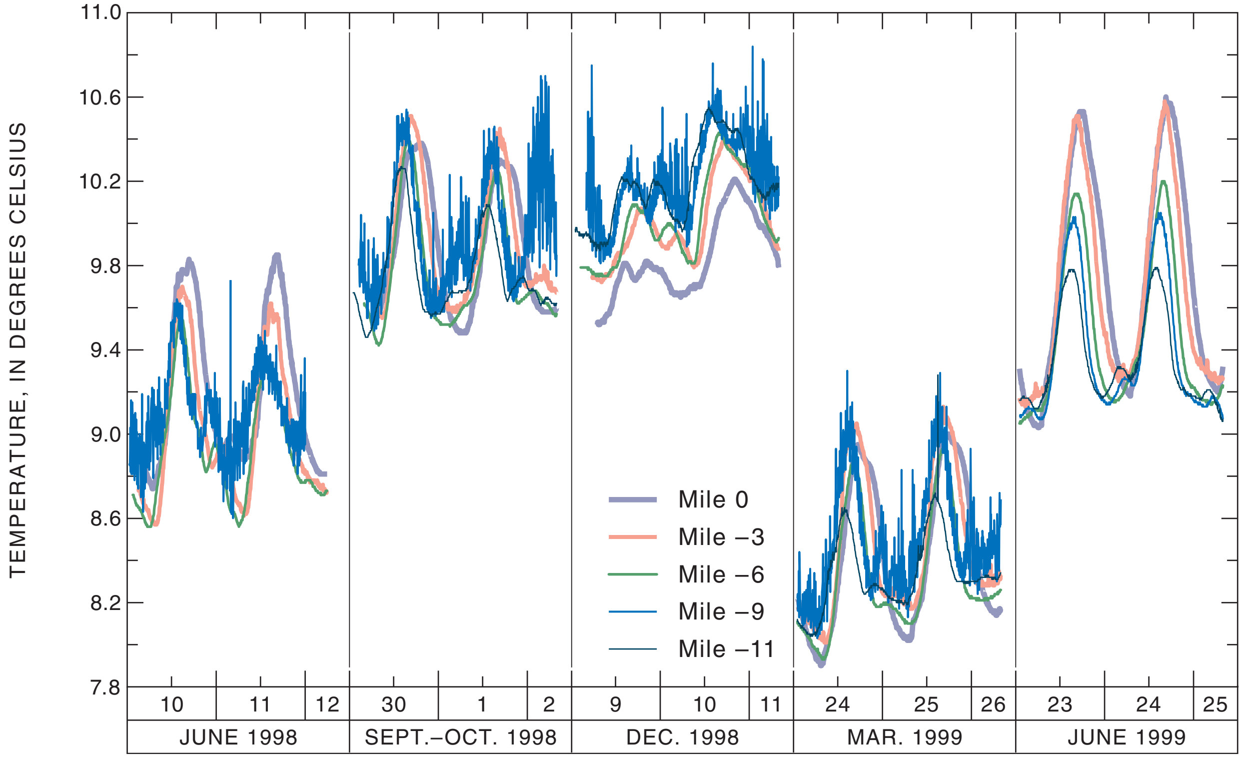

Figure 6. Seasonal temperature data collected from the tailwater of Glen Canyon Dam during June, September-October, and December 1998, and March and June 1999.

The difference in average temperature between June 1998 and June 1999 indicates interannual temperature variation. The high short-term variability (noise) in the data sets collected at the -9-mile site in June, September-October, and December 1998, and March 1999 is due to the placement of the datalogger near and just upstream from a spring. The warm water from the spring caused the frequent excursions above the colder water coming from Lake Powell. In June 1999, the site of deployment was moved several meters farther upstream from the spring and the "noise" was not observed.

Measurements of specific-conductance profiles made in the forebay of Glen Canyon Dam on the dates of the tailwater measurements are shown in figure 7. Conductivity stratification is complex and reflects, in part, the thermal stratification and salinity that control the depth of annual mixing. Thermal stratification was strong in June (1998 and 1999) and September 1998. The epilimnion had eroded by December 1998; however, the depth of mixing was compromised by salinity contributions to density. By March 1999, the epilimnetic layer had cooled, and the thermal discontinuity (fig. 5) had eroded deeply and entrained more saline deep water (fig. 7) so that the conductivity of water passing through the penstocks reached its maximum for the period of the study.

Specific-conductance measurements made at the five sites in the Colorado River tailwater below Glen Canyon Dam are shown in figure 8. Specific-conductance data show no regular daily pattern. The variability among seasons and within days is due to changes in salinity of the water passing through the dam from Lake Powell. As with temperature, the high short-term variability (noise) in the data sets collected at the -9-mile site in June, September-October, and December 1998, and March 1999 is due to the placement of the datalogger near and just upstream from a spring. The spring water diluted the water from Lake Powell that had a higher specific conductance. The noise was not observed after the measurement site was moved several meters farther upstream from the spring in June 1999.

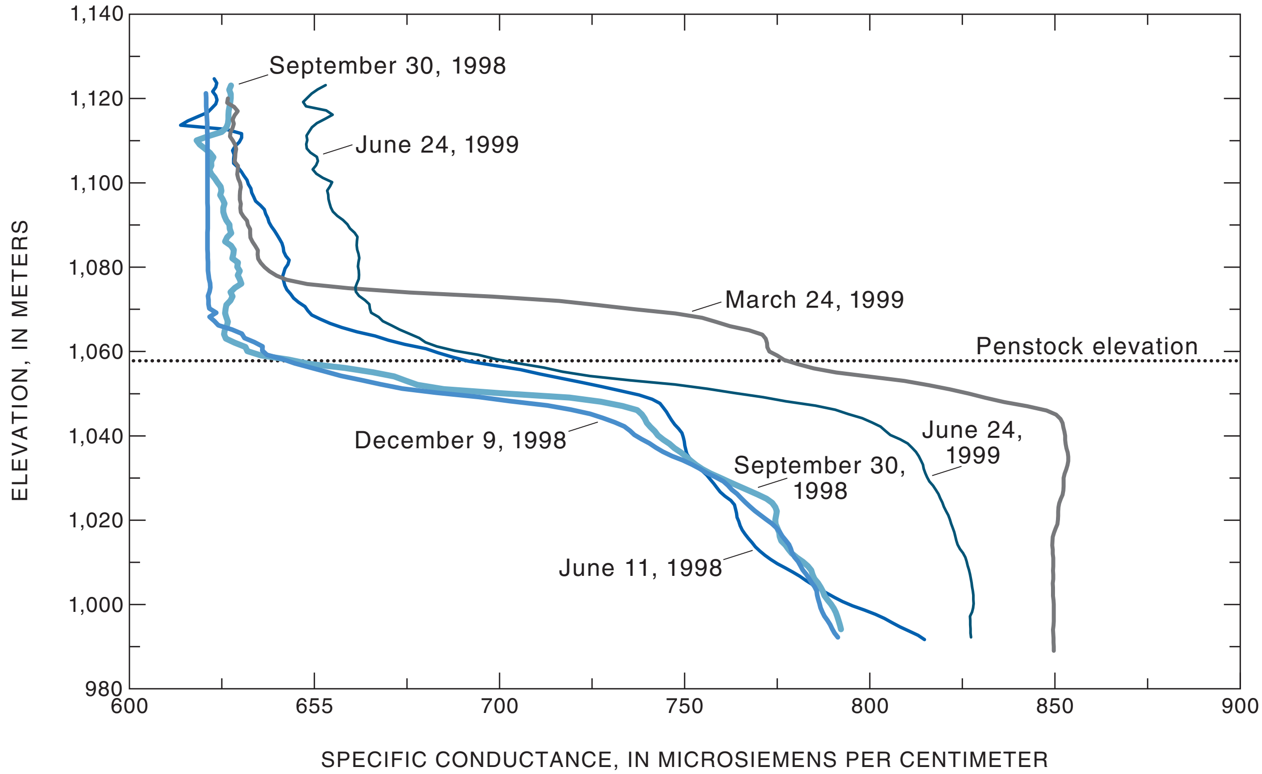

Figure 7. Selected specific-conductance profile data collected from the forebay of Glen Canyon Dam.

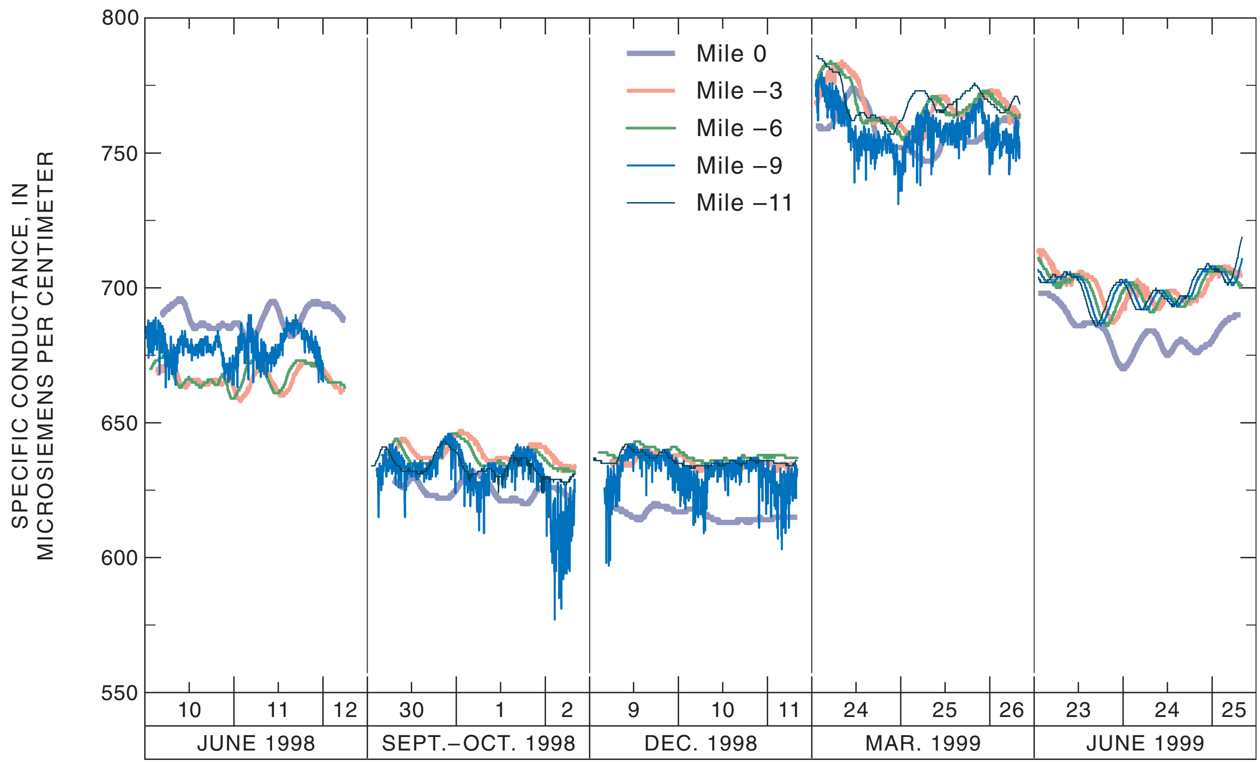

Figure 8. Seasonal specific-conductance data collected from the tailwater of Glen Canyon Dam during June, September-October, and December 1998, and March and June 1999.

SUMMARY

The major observations during this study were:

Forebay Measurements—

(1.) Thermal stratification in June and September 1998, and March 1999 is sufficient to isolate water at hypolimnetic depths from the atmosphere and from lighted zones where photosynthesis releases oxygen.

(2.) The decrease in dissolved-oxygen concentration at penstock depth from June to September 1998 reflects the consumption of oxygen. The increase in oxygen concentration from March to June 1999 results from mixing during unstratified winter conditions.

(3.) By March 1999, the epilimnetic layer had cooled, and the thermal discontinuity had eroded deeply enough that the water passing through the penstocks had reached its minimum temperature and maximum specific conductivity for the period of study.

Tailwater Measurements—

(1.) The decrease in average pH and the variation in dissolved-oxygen concentrations through time reflects seasonal changes in Lake Powell at the depth of the penstocks.

(2.) Specific conductance showed no regular daily pattern.

(3.) Daily warming was observed on all dates. The maximum warming during the day (approximately 1.3°C) occurred in June, near the summer solstice.

(4.) The difference in average temperature between June 1998 and June 1999 documents interannual temperature variation.

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